COPY NO. ____
TP6558

# INTERIM TECHNICAL REPORT

# ACTIVE VIBRATION ISOLATOR

15 OCT 1970

STAT

hycon

700 ROYAL OAKS DRIVE,
MONROVIA, CALIFORNIA 91016

COPY NO._____

**TP6558**

# INTERIM TECHNICAL REPORT

# ACTIVE VIBRATION ISOLATOR

15 OCT 1970

STAT

hycon

*700 ROYAL OAKS DRIVE,*
*MONROVIA, CALIFORNIA 91016*

Technical orders are normally distributed promptly after printing. Date(s) shown on the title page (lower right) are for identification only. This is not a distribution date. Processing time sometimes causes distribution to only appear to have been delayed.

# LIST OF EFFECTIVE PAGES

INSERT LATEST CHANGED PAGES. DESTROY SUPERSEDED PAGES.

NOTE: The portion of the text affected by the changes is indicated by a vertical line in the outer margins of the page. Changes to illustrations are indicated by miniature pointing hands or shaded areas.

Dates of issue for original and changed pages are:

ORIGINAL . . 0 . . 15 OCTOBER 1970

TOTAL NUMBER OF PAGES IN THIS PUBLICATION IS 30 CONSISTING OF THE FOLLOWING:

| Page No. | Change No. |
|---|---|
| Title | 0 |
| A | 0 |
| i | 0 |
| ii blank | 0 |
| iii | 0 |
| iv blank | 0 |
| 1-1 - 1-2 | 0 |
| 2-1 - 2-8 | 0 |
| 3-1 - 3-4 | 0 |
| 4-1 - 4-2 | 0 |
| 5-1 - 5-8 | 0 |

* The asterisk indicates pages changed, added, or deleted by the current change.

Upon receipt of the second and subsequent changes to this technical order, personnel responsible for maintaining this publication in current status will ascertain that all previous changes have been received and incorporated. Action should be taken promptly if the publication is incomplete.



Declassified in Part - Sanitized Copy Approved for Release 2012/10/16 : CIA-RDP79B00873A000800020001-4

TABLE OF CONTENTS


| Section | | Page |
|---|---|---|
| | FOREWORD | iii |
| 1 | INTRODUCTION AND SUMMARY | 1-1 |
| 2 | DESIGN CONSIDERATIONS | 2-1 |
| | 2.1 Two Phase Program | 2-1 |
| | 2.2 Early Design Decisions | 2-3 |
| 3 | HARDWARE DESCRIPTION | 3-1 |
| | 3.1 General | 3-1 |
| | 3.2 Component Specifications | 3-1 |
| | 3.3 Structure | 3-3 |
| | 3.4 Electronics | 3-3 |
| | 3.5 Control Panel | 3-3 |
| 4 | ALIGNMENT AND PRELIMINARY TESTING | 4-1 |
| 5 | CONFIDENCE TESTING | 5-1 |


LIST OF ILLUSTRATIONS


| Figure | | Page |
|---|---|---|
| 2-1 | One Arc-Second Stabilization Capability, Rate vs Exposure Time | 2-2 |
| 2-2 | Typical Vibration Environment | 2-4 |
| 2-3 | Design Limits for Translational Vibration | 2-7 |
| 3-1 | Active Vibration Isolator Assembly with KS-72 Camera | 3-2 |
| 3-2 | Control Panel | 3-4 |
| 5-1 | Instrumentation Setup for Measuring Transmissibility | 5-2 |
| 5-2 | Transmissibility | 5-3 |
| 5-3 | Pitch Transmissibility, AVI Serial No. 001 | 5-4 |
| 5-4 | Roll Transmissibility, AVI Serial No. 001 | 5-5 |
| 5-5 | Pitch Transmissibility, AVI Serial No. 002 | 5-7 |
| 5-6 | Roll Transmissibility, AVI Serial No. 002 | 5-8 |

## FOREWORD

This report was prepared by Hycon Company, 700 Royal Oaks Drive, Monrovia, California 91016, under contract [redacted] It is the interim report covering the design and test of two breadboard vibration isolation systems during the period of 8 July 1969 to 14 May 1970. The work was administered under the direction of the Air Force Avionics Laboratory (AVRS), Air Force Systems Command, Wright Patterson Air Force Base, Ohio. [redacted] represented the program office. The work performed is for the phase I portion of a two-phase developmental contract. The work was accomplished in accordance with the Statement of Work, Exhibit A, 11 June 1969, [redacted] entitled, "Electromagnetic Vibration System".

STAT STAT STAT

The principal contributors to the design, fabrication, and testing of the Active Vibration Isolator System are listed as follows:

STAT

Program Manager
Contractor Administrator
Project Engineer
Mechanical Engineering
Electrical Engineering and Systems Engineering
Vibration Engineer

[redacted]



Declassified in Part - Sanitized Copy Approved for Release 2012/10/16 : CIA-RDP79B00873A000800020001-4

# Section 1

## INTRODUCTION AND SUMMARY

Motion, and specifically rotational motion, is a limiting factor on acuity in modern aerial reconnaissance photography. In aerial cameras with long focal lengths, today's high-definition emulsions require exposures of up to one-hundredth of a second. These longer exposures lead to more smear from a given level of motion. In low altitude reconnaissance missions, evasive maneuvers and aerodynamic buffeting often cause unacceptable smear even where higher speed emulsion and short exposures are used. As new films, lenses, and FMC devices are developed, the need for better mounting and isolation systems becomes even more apparent.

Typically, the methods of mounting a camera in the air vehicle are as follows:

a. Hard-mounted directly to aircraft structure
b. Soft-mounted on passive vibration isolators
c. Mounted on gyro-stabilized gimbal platforms

None of these approaches totally meets the requirements for mounting high-acuity cameras in high-performance aircraft. With the hard-mounted approach, all aircraft vibrational inputs are transmitted directly to the camera. With the soft-mounted, passive isolation approach, high frequency vibration inputs are attenuated, but the low frequency components are not isolated, and inputs at mount resonance are amplified.

The gyro-stabilized gimbal system provides low frequency vibration attenuation, but the approach is complex and requires large packaging volumes. A performance drawback inherent in the gimbal system approach is that the system is extremely sensitive to center-of-gravity shift resulting from film transportation.

To meet the need for an improved camera isolation system, Hycon had developed a motion isolation system employing electromagnetic actuators acting in parallel with coil springs. Angular accelerometers and rate gyros were used to sense rotary motion. The system was called the Wide-Band Stabilizer.* Under phase I of a two-phase contract to the United States Air Force Avionics Laboratory, Hycon has designed, fabricated, and tested two breadboard motion isolators known as the Active Vibration Isolator (AVI) using the Wide-Band Stabilizer principles.

*Patent applied for

The design goal was to limit camera motion in pitch and roll to 1 second of arc during one-hundredth second of camera exposure (0.5 milliradian/second). In actuality, the Hycon AVI betters this performance over a wide variety of input rates and frequencies. The AVI is designed to provide motion rejection even if the input motion approaches several times that of a typical reconnaissance type aircraft. Another inherent advantage of the Hycon AVI design is the ability to reduce camera-generated torques by 90 to 95 percent.

The transient response of the AVI is fast enough to allow duty-cycle operation (recentering between camera exposures), which is a bandwidth-extending capability.

The AVI is smaller and lighter than the A-28 mount (typical gimbal type) while providing greatly increased bandwidth and performance. The AVI is inherently smaller and lighter than a hydraulic or pneumatic type because of the electromagnetic actuators, which require no external compressors, regulators, or cooling apparatus.

The upper and lower frames, which were necessary to match the mounting of the A-28 for test purposes, could be simplified or eliminated depending on the mounting stiffness of the camera and vehicle.

Use of the AVI was well within the capabilities of an average technician. A simple bracket alignment fixture allowed a technician to switch cameras in a short time with simple hand tools. Minor actuator adjustments and addition of a balancing weight allowed switching from a KS-72 to a KS-87 camera with no loss in performance.

Control of the AVI requires only two signals to implement the standby (caged) and operate positions. These could be controlled by a simple switch or slaved to the camera for automatic operation.

The low power consumption of the AVI allows easy retrofit on power-limited operational aircraft.

In total, the electromagnetic AVI meets the Air Force's need for a simple, light, low-power high-performance camera isolation system.

# Section 2

# DESIGN CONSIDERATIONS

## 2.1 TWO PHASE PROGRAM.

The development of two breadboard models of the Active Vibration Isolator is Phase I of a two phase program to improve aerial reconnaissance camera performance by reducing camera input motion. Phase II would develop prototype hardware capable of being produced in quantity. Phase I required Hycon to design and confidence test the breadboard systems prior to shipment to Wright-Patterson Air Force Base (WPAFB) for Dynamic Analyzer (DA) testing and flight testing in a C-131 aircraft. The KS-87 camera with 18-inch lens was specified as the camera to be mounted in the AVI during DA and flight testing. The photography from this system would be the criterion for evaluating performance.

2.1.1 Performance Goals. Dynamic Analyzer environment test levels, flight input levels and AVI performance levels were not fully defined for Phase I. Hence, Hycon developed a performance design specification that established realistic isolation performance goals and representative environment inputs based on known needs for aerial reconnaissance cameras.

2.1.2 Goals for Rotational Inputs. The worst case values assumed for the active design included the following aircraft rotational inputs:

| Axis | Frequency Band | Magnitude |
|---|---|---|
| Pitch | 0 - 1 Hz | ±2.5° |
| | 1 Hz and up | 200 mrad/sec |
| Roll | 0 - 1 Hz | ±2.5° |
| | 1 Hz and up | 200 mrad/sec |

At low frequencies, total stroke of the AVI actuators is the limiting factor and, therefore, the specification is in terms of permissible angular excursion. The ±2.5° limits were taken as practical limits for Phase I equipment. At intermediate and high frequencies the information documented in Technical Report AFAL-TR-67-277 was used as a guide. The selected level of 200 milliradians/sec is approximately two times greater than the typical rates of reconnaissance aircraft noted in this report.

The design goal set for the AVI when experiencing rotational inputs is to reduce camera motion to 1 arc-second for a 1/100 second exposure period (see figure 2-1). This corresponds to an angular rate at the camera of less than 0.5 milliradian/sec. Obviously, this extremely low level of residual rate cannot be achieved over all input conditions; therefore,

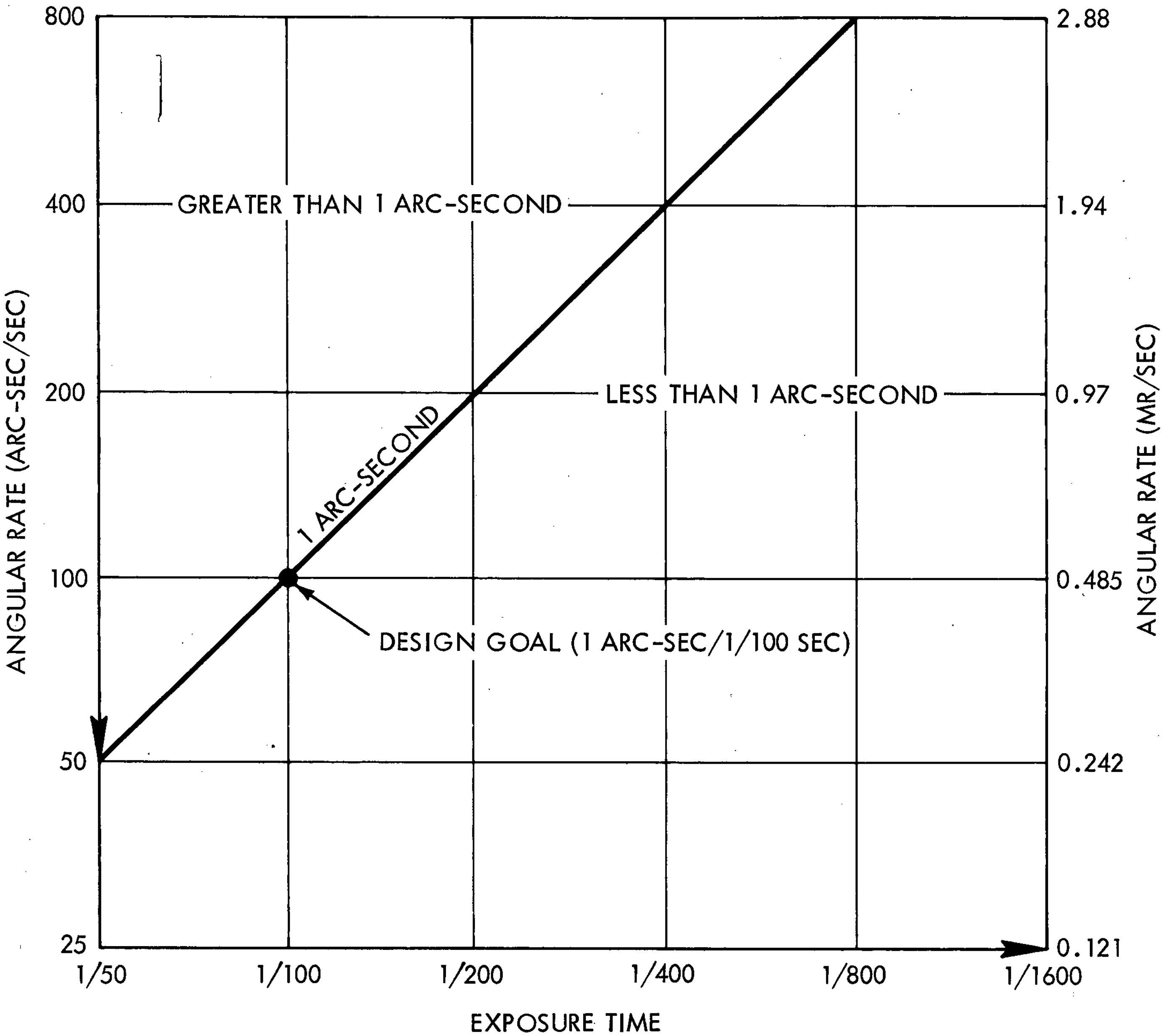


Figure 2-1. One Arc-Second Stabilization Capability, Rate vs Exposure Time

the actual design goal was to produce the highest level of rejection of input rates (lowest transmissibility) possible over the entire frequency band.

Phase I did not include an active yaw isolator, so, for the purposes of setting design requirements, this axis was to be passively isolated without degradation of pitch and roll performance.

2.1.3 Goals for Translational Inputs. For the linear (translational) vibration environments, three levels of vibration were provided by the Avionics Lab representing three classes of aircraft:

a. High performance tactical aircraft.
b. Low performance cargo and bomber aircraft
c. High altitude reconnaissance aircraft

These inputs are shown in figure 2-2 in terms of peak velocity as a function of frequency. For design purposes, the upper limits of the composite of the three curves were used as design limits. Figure 2-3 is the composite curve for the three types of aircraft.

The design goal set for the AVI is to attenuate translational inputs to the maximum possible extent using passive isolation techniques commensurate with the primary goal of achieving best angular isolation in the pitch and roll axes.

## 2.2 EARLY DESIGN DECISIONS

2.2.1 Phase II Effort Performed in Phase I. The phase I effort, as outlined in Hycon's proposal to the Air Force Avionics Laboratory, was to develop a breadboard isolation system capable of attenuating vibration inputs above 1.0 Hz about the pitch and roll axes. The isolation system was to be used in conjunction with a standard A-28 mount, which would provide motion stabilization for input disturbance frequencies below 1.0 Hz.

2.2.2 A-28 Mount. Evaluation of this approach during the initial design analysis indicated that combining the dynamics of these two systems would cause a serious problem. With the proposed mechanization, the AVI and A-28 systems would be controlling coincident axes of rotation which would result in interaction between the two servo systems. This interaction would cause servo stability problems and the flight test results would be difficult to evaluate. Because of these projected problems it was concluded that the AVI for phase I should be self-contained and not incorporate the A-28 mount. This decision resulted in design and fabrication of the upper and lower mounting frames now incorporated into the phase I system. The frames serve as interface adapters and mechanically tie the electromagnetic isolator system together.

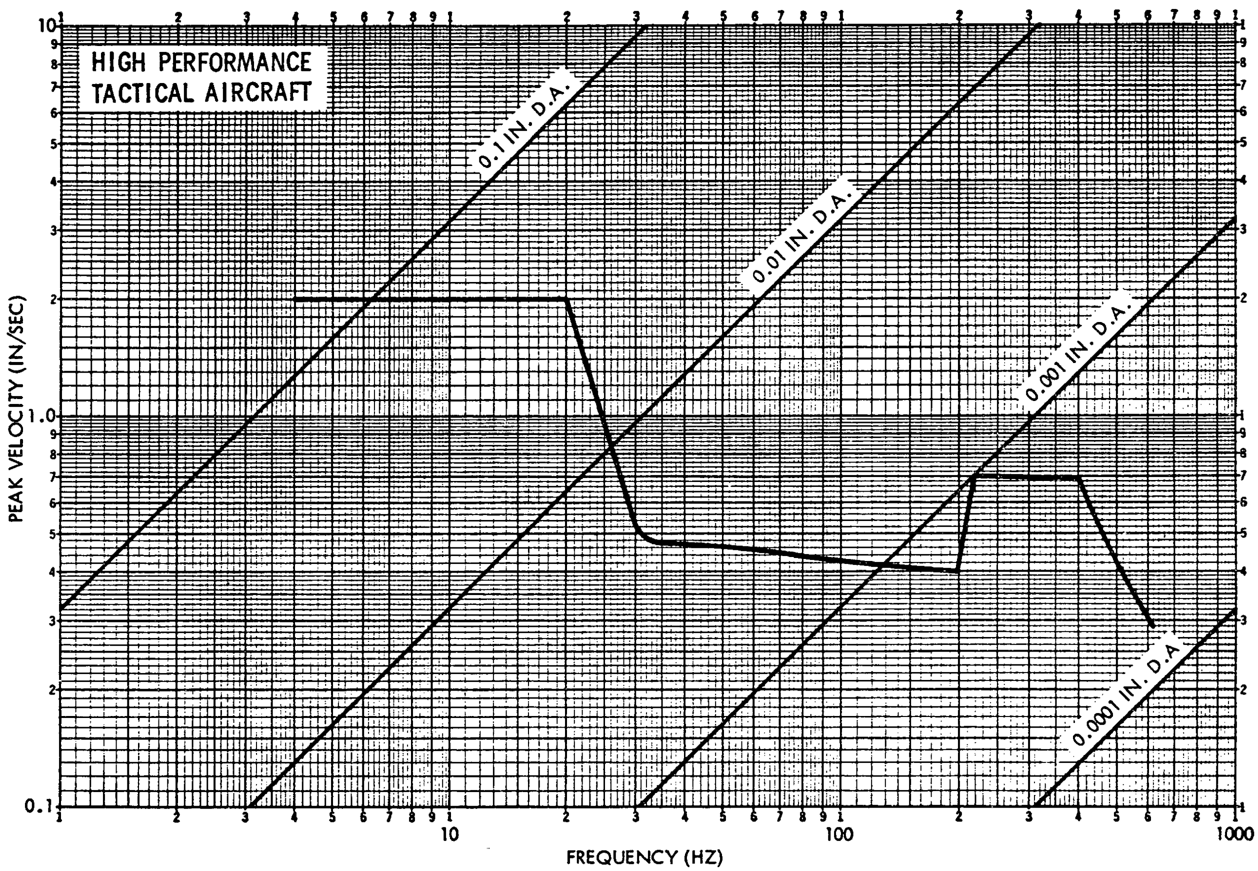


Figure 2-2. Typical Vibration Environment (Sheet 1)

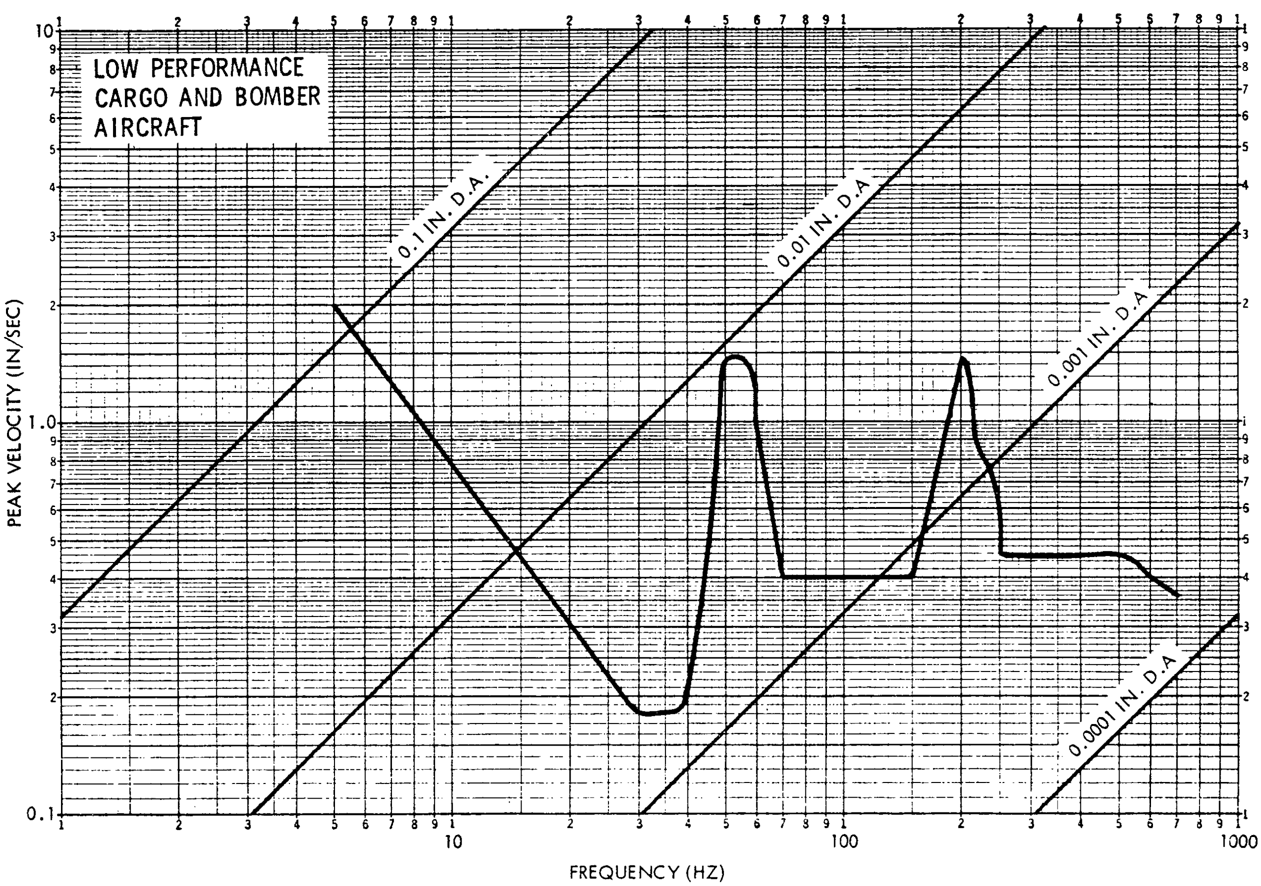


Figure 2-2. Typical Vibration Environment (Sheet 2)

TP6558

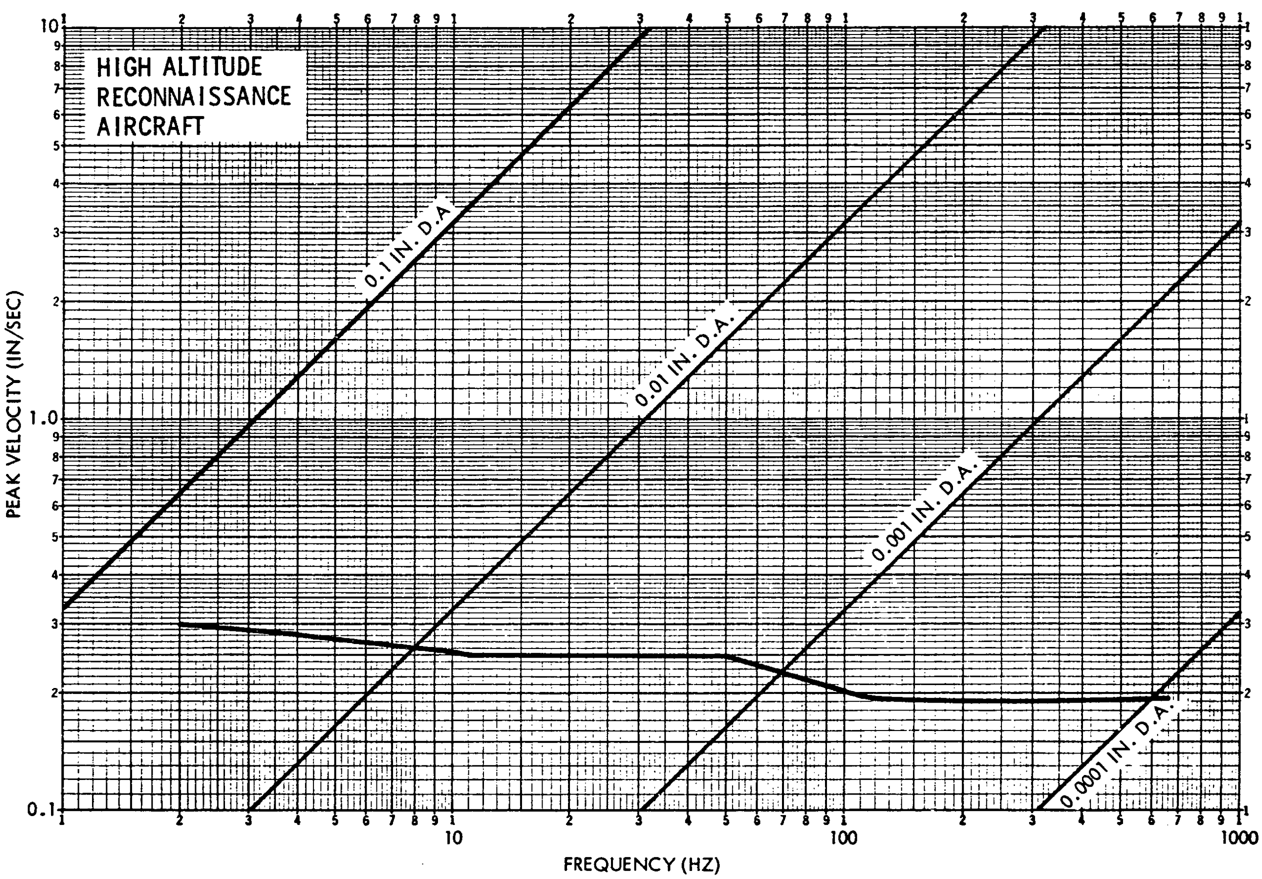


Figure 2-2. Typical Vibration Environment (Sheet 3)

Declassified in Part - Sanitized Copy Approved for Release 2012/10/16 : CIA-RDP79B00873A000800020001-4

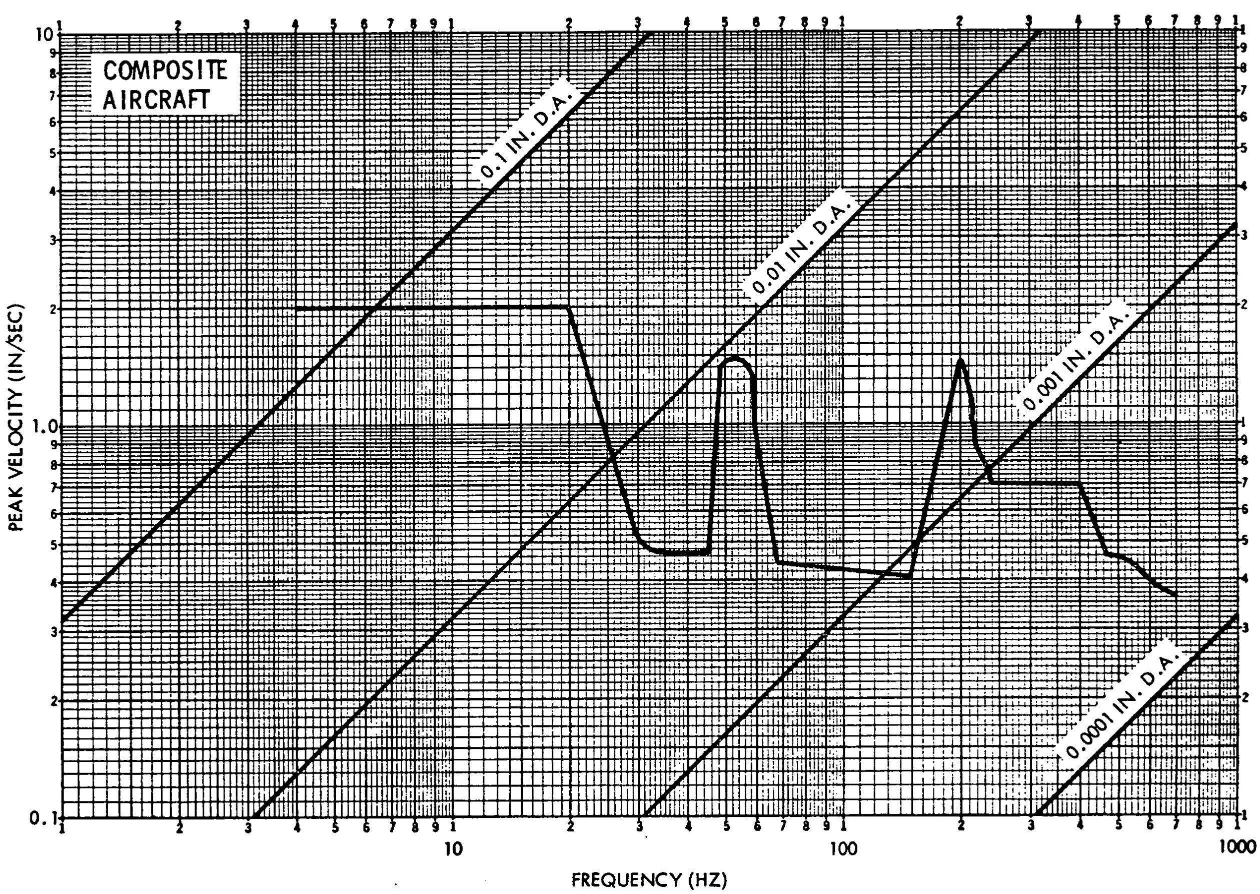


Figure 2-3. Design Limits for Translational Vibration

TP6558

2.2.3 Low Frequency Operation. Since imagery was to be a primary criterion for evaluating mount performance, it was apparent that identification of vibrational frequency components causing smear would be extremely important. Due to the deletion of the A-28 mount, evaluation of the Hycon AVI capability would be very difficult because of low frequency (<1 Hz) picture smear. Thus it was apparent that only with a low frequency stabilization capability could the 100 arc-sec/sec isolation performance be demonstrated using imagery from a KS-87 camera with an 18-inch lens cone. Tests performed during conceptual development demonstrated that rotary motion isolation at 1 Hz is improved by a factor of 3 with the incorporation of rate gyros. A natural consequence of rate gyro motion sensing is that performance is not only improved at 1 Hz and above but is also improved for frequencies less than 1 Hz. In this instance, the system isolation capability can be extended down to 0.01 Hz. A 0.01-Hz stabilization capability is one of the requirements for phase II.

2.2.4 Long-Stroke Actuators. The original phase I proposal called for an actuator stroke of ±0.25 inch. The stroke of the actuator must be long enough to handle combined rotary motion and translational vibratory motion along the vertical axis. Early analysis of available electromagnetic actuators revealed that no off-the-shelf item would provide adequate performance. Therefore, Hycon designed an actuator with a ±0.5-inch stroke. Low friction is required because friction creates disturbance torques that cause errors as a function of aircraft input.

# Section 3

# HARDWARE DESCRIPTION

## 3-1. GENERAL

Figure 3-1 is a photograph of the Active Vibration Isolator (shown with a KS-72 camera and mounted on a test fixture). The upper and lower frames serve as application adapters for the camera and aircraft interfaces. Connecting the two frames are four electromagnetic actuator and spring assemblies. The springs provide support for the camera load, whereas the actuators apply up or down forces on command from the electronics package. The rotary sensors, consisting of gyros and accelerometers, are mounted to the upper frame. Mounted to the lower frame are the servo electronics and power supply module and four power amplifier and damping network assemblies. System damping and long-term position are derived from electrical signals generated by the linear position transducers mounted on the electromagnetic actuators.

## 3.2 COMPONENT SPECIFICATIONS

A brief description and a list of parameters are provided for the important component parts in the paragraphs that follow.

3.2.1 Load Springs. The load springs are of a coiled helix design with squared ground ends. The springs are designed for low axial stiffness and maximum surge frequency. Four springs are used in each system. They are mounted on top of the actuators although they carry loads in parallel with them. They have a spring rate of 30 lb/in and a free length of 2.85 inches.

3.2.2 Electromagnetic Actuators. The electromagnetic actuators are push-pull type dc solenoids. The actuator armatures are precision ground and are guided by ball bushings to minimize friction. U-joints are used at both ends of the actuator to allow free movement during motion inputs. Four electromagnetic actuators are used on each system, each with a stroke capability of ±0.5 inch.

3.2.3 Angular Accelerometers. The angular accelerometers consist of fluid-filled toroids coupled with sensors and electronics. The angular acceleration output signal is proportional to the Newtonian reaction force set up by the fluid when the toroid is accelerated about its input axis. Two angular accelerometers are used, one in the pitch axis and one in the roll axis.

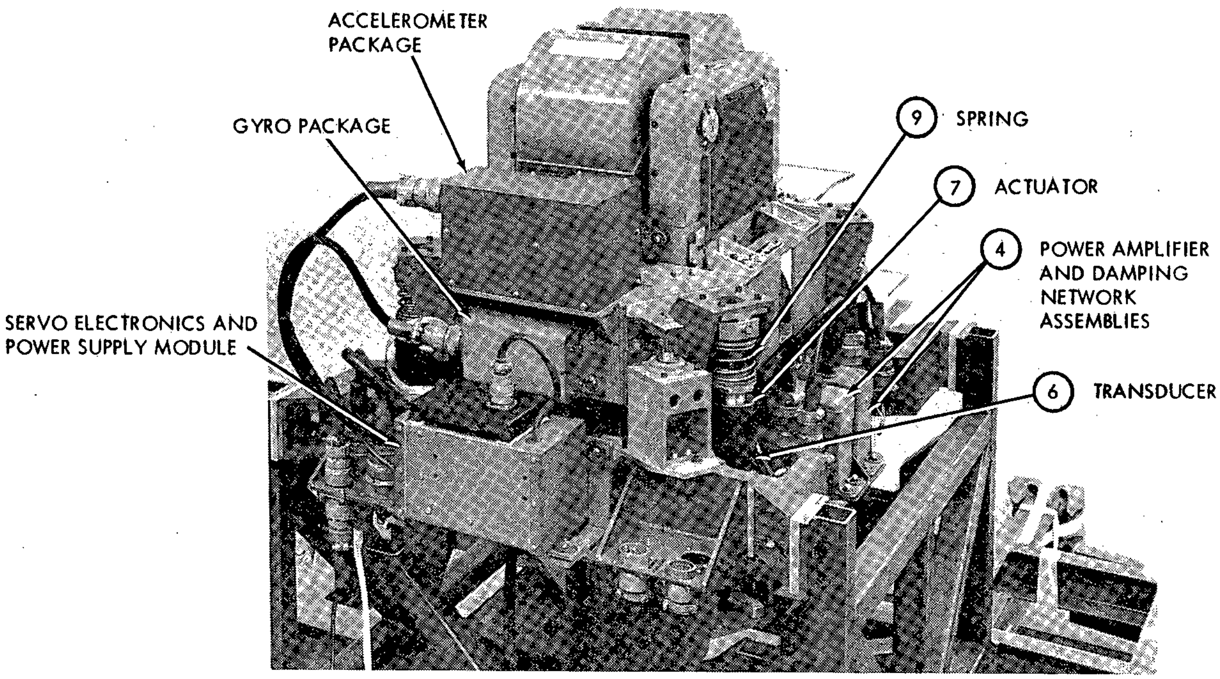


Figure 3-1. Active Vibration Isolator Assembly with KS-72 Camera

3.2.4 Rate Gyros. The rate gyros are torsion-bar restrained units that are suspended in fluid that provides internal damping. The gyros provide rotary motion signals for isolation down to very low frequencies. Two rate gyros are used in each system, one for the pitch axis and one for the roll axis.

3.2.5 Position Transducers. The position transducers are linear variable differential transformers (LVDT). The transducers are mounted in parallel with the electromagnetic actuator; four are required for each system.

3.2.6 Radial Isolators. Since the actuators have U-joint fittings, the upper frame and camera require support in a horizontal plane. Without this support, the upper frame would be unstable and fall over. The requirements for the radial isolators, then, are to provide longitudinal and lateral support to the upper frame without coupling linear vehicle motion into rotary torques to the upper frame. The design employs modified elastomer mounts incorporating ball bushings. A polished shaft affixed to the upper frame passes through the mount and is supported by the ball bushings.

3.2.7 Snubbers. Snubbers are used to restrain the upper frame when an out-of-stroke condition exists. The snubbers are located in the actuator assembly.

## 3.3 STRUCTURE

The structure consists of the upper frame that mounts the camera and the lower frame that mounts in place of the A-28 mount in the vehicle. The upper frame was designed for the required stiffness and to allow easy removal and replacement of cameras. Conversion from KS-72 to KS-87 mounting was also considered. A camera maintenance man can remove and replace either model camera in a short time with only simple hand tools. The only alterations required to convert from KS-72 to KS-87 use are adjustment of actuators and position transducers and addition of a small balance weight.

Stiffness of the upper frame and camera combination is important, because any resonance excited by the actuators and sensed by the angular accelerometers appears in the acceleration feedback loop. A major resonance was found in the KS-72 at approximately 140 Hz and consequently the upper frame was made stiff to the degree that the camera stiffness was the limiting factor in the design. No further improvement in motion rejection using acceleration feedback could be attained without modifying the camera.

## 3.4 ELECTRONICS

The electronics consist of signal amplifiers and power amplifiers. The signal amplifiers receive inputs from the angular accelerometers, rate gyros, and linear transducers. The signals are amplified and shaped and then used to drive the power amplifiers. Four power amplifiers are used, one for each actuator.

The power amplifiers used to drive the electromagnetic actuators are of a pulse-width-modulated, duty-cycle design. The design is a modification of a power amplifier used on other Hycon systems and was chosen for its high power efficiency. The high efficiency is inherent in this design approach and is based on the modulation of a 16-kHz carrier frequency through the use of high-speed switching circuits.

## 3.5 CONTROL PANEL (See figure 3-2.)

System operation is controlled remotely by a three-position rotary switch mounted on a control panel. The indicated mode positions on the panel are OFF, STANDBY, and ON. In the OFF position, no power is applied to the system. In the STANDBY position, power is applied to the system, but the stabilization servo loops are not enabled. During the STANDBY mode of operation, the electronic damping and long-term position loop are applied by feeding amplified electrical signals from the position transducers back to the electromagnetic actuators. The purpose of the electronic damping is to limit translational excursions along the vertical axis. The STANDBY mode is used during system warmup to allow for thermal and electronic transient stabilization.

In the ON position, all circuits are enabled and the system performs its intended task of stabilizing a supported camera.

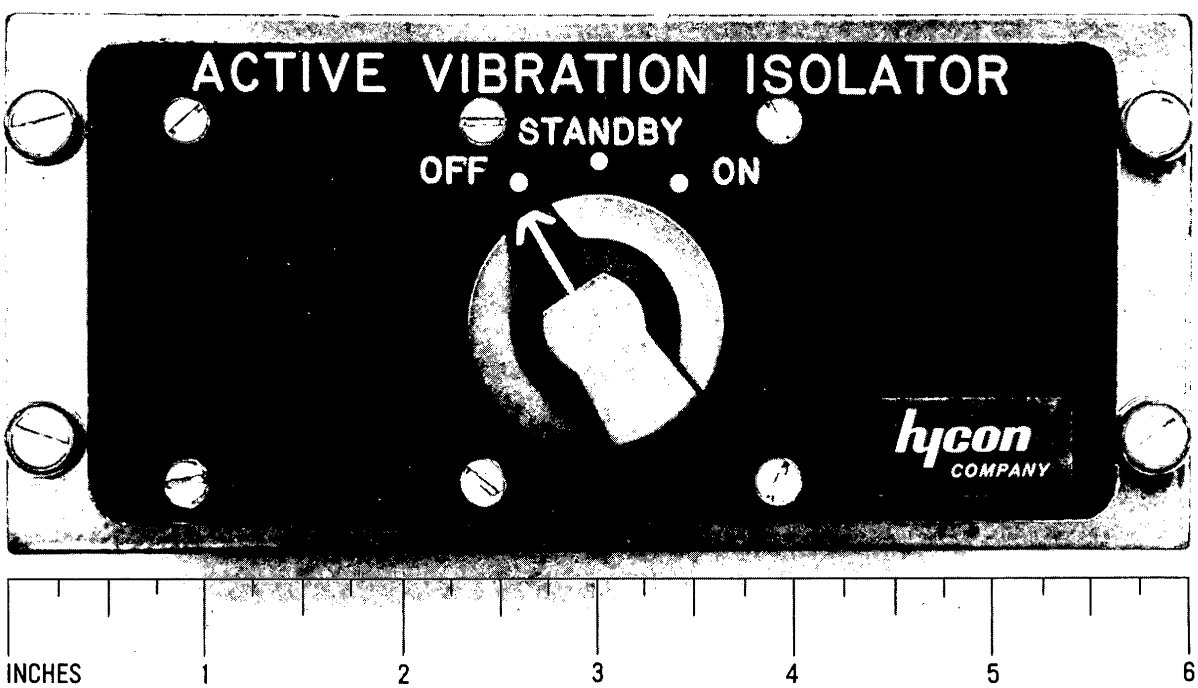


Figure 3-2. Control Panel

## Section 4

## ALIGNMENT AND PRELIMINARY TESTING

Alignment of the AVI consisted of mechanical design verification, reduction of all friction, balancing, and design optimization. Since a KS-87 camera was not available, alignment and preliminary testing were performed using a KS-72 camera with an 18-inch lens cone.

During alignment, mechanical design verification consisted of checking the mechanical tolerances of the actuator, U-joints, load springs, rubber snubbers, and position transducer assemblies. With the KS-72 mounted in the upper frame, the actuators were adjusted to be in the center of their strokes. The rubber snubbers were adjusted to keep the actuator armatures from bottoming out during heavy loading. The radial isolators were then located equidistant from the center of gravity of the total system.

Reducing the residual friction of the mount required designing the main load springs so that they would not preload the actuator shafts radially against the ball bushings. The ends were closed so that the spring could only exert vertical forces. The elastomeric isolators of the radial isolator assembly were modified during the alignment stage to include two ball bushings to guide the shafts instead of one.

Balancing means placing the center of gravity (cg) of the total spring-supported load at a location such that linear inputs give rise only to linear outputs. Using a cg mount, no net torques are generated during translation. It has been found that, in the event of a residual cg offset, the AVI reduces the generated torques by 90 to 95 percent. Once the sensor and upper frame are initially balanced, the system is highly insensitive to reasonable cg offsets, such as would occur when the camera transports film. The center of the four load springs should define a point at the cg, and a line through the two radial isolators should also go through the cg. Balancing can best be accomplished by using a dynamic input at translational resonance, since, at that frequency, the translational input is amplified by the Q of that passive mode. In the case of vertical shimming, a side-to-side input was used, and the radial isolators were shimmed vertically to minimize cross coupling into roll. Balancing fore and aft and side to side was done by measuring the static balance of the camera and then placing it properly in the upper frame assembly.

Design optimization consisted of checking out the various servos and subsystems to get the best possible performance in the time allotted. The servos were completed in the following order: long term position loops, active damping, acceleration loops, and acceleration plus rate loops.

With all other electronics disabled, each position transducer was adjusted for 0 volts output at the center of the adjacent actuator's stroke. The gain of the position loop was set to a value calculated to have no adverse effect on low frequency stabilization. The loop was then activated and the AVI manually displaced. When released, the time required for return to zero position was verified to be as calculated.

Next, the active damping circuits were connected and transmissibility curves were run to verify that the resonant peak of the passive isolators was reduced as calculated. This peak occurs at about 3 Hz. Transmissibility curves are run by measuring input motion of the test source and output motion of the AVI and plotting points at several frequencies between 1 and 25 Hz.

With the position loop and damping circuits connected and activated, the acceleration feedback circuits are then activated. The loop is adjusted to critical gain by finding the level that causes oscillation and then backing off just enough to stop oscillation at all actuator positions and motion input levels. Transmissibility curves were run.

At this point it was found that servo compensation had to be changed from that calculated due to the nature of the camera stiffness. The ultimate motion rejection achievable using acceleration feedback is limited by the high frequency stiffness characteristics of the upper frame and camera combination. If a high-Q resonance exists at, say, 80 Hz, then the performance is limited over that attainable with a resonance at 250 Hz because less gain can be added before instability occurs. Using the KS-72 camera (with an 18-inch lens cone), the lowest resonance occured at about 140 Hz, and the servo gain was adjusted accordingly. The results allow between 10- and 30-to-1 reduction across the midband frequencies of 1 to 15 Hz. A 10-to-1 reduction is 90 percent rejection while 30-to-1 reduction is 97 percent rejection of input motion.

The rate feedback circuits were activated, critical gain adjusted, and transmissibility curves run. Testing proved that the addition of rate feedback to a mount stabilized by acceleration feedback adds rejection from the low frequencies up to the frequency at which active-to-passive crossover takes place. Above 1 Hz, the improvement is generally between 2-to-1 and 4-to-1. Below 1 Hz, the curve remains essentially flat to 0.1 Hz. Below 0.1 Hz, the stabilizer presents a first-order rolloff to the input motion.

## Section 5

## CONFIDENCE TESTING

Confidence testing of the AVI consisted of subjecting the stabilizer to pitch and roll inputs separately and measuring transmissibility in each axis. The testing of the AVI was carried out on a two-axis flight simulator constructed by Hycon. Since a KS-87 camera was not available, confidence testing was performed using a KS-72 camera with an 18-inch lens cone.

There are six possible inputs and six possible outputs (R, P, Y, x, y, and z). In vertical photography, pitch and roll camera motion give rise to the greatest amounts of smear, because the product of the pitch or roll rate times the lens focal length gives a linear smear velocity that is generally larger than any other contributor. Yaw smear velocity is the product of yaw rate and the distance from the center of the format to the point of interest in the format. Linear vibration rates generally cause no degradation in photography except for their effect on the sensor system mechanics.

There are three major considerations in the application of a two-axis stabilizer.

a. Transmissibility - Transmissibility is the ratio of output motion to input motion at a given frequency. The lower the transmissibility across the broad frequency range of interest, the lower will be the rms residual rate and therefore the lower the smear.

b. Transient Response - In applications where the stabilizer is to be caged between frames or caged after a finite time interval, the AVI must recover from the caged condition in time to stabilize the input rates for the next shutter exposure. The best transient response (fastest recovery) will be from a system having a wide bandwidth, since bandwidth is inversely related to transient response.

c. Linearity - Linearity is the measure of how well low-amplitude inputs (1 to 5 mr/sec) are attenuated compared with high-amplitude inputs (10 mr/sec and up). A stabilizer that uses low-friction actuators will be able to work down to the lower input levels.

The transmissibility, transient response, and linearity were all measured using the flight simulator. The test setup for transmissibility is shown in figure 5-1.

Angular accelerometers were used to measure the simulator input motion and the camera motion above 1 Hz. Below 1 Hz, the stabilizer was caged and rate gyros were used to measure the input.

The flight simulator consists of a heavy base supporting a two-axis bearing gimbal. The bearing gimbal supports a test bed that is stiff to 50 Hz.

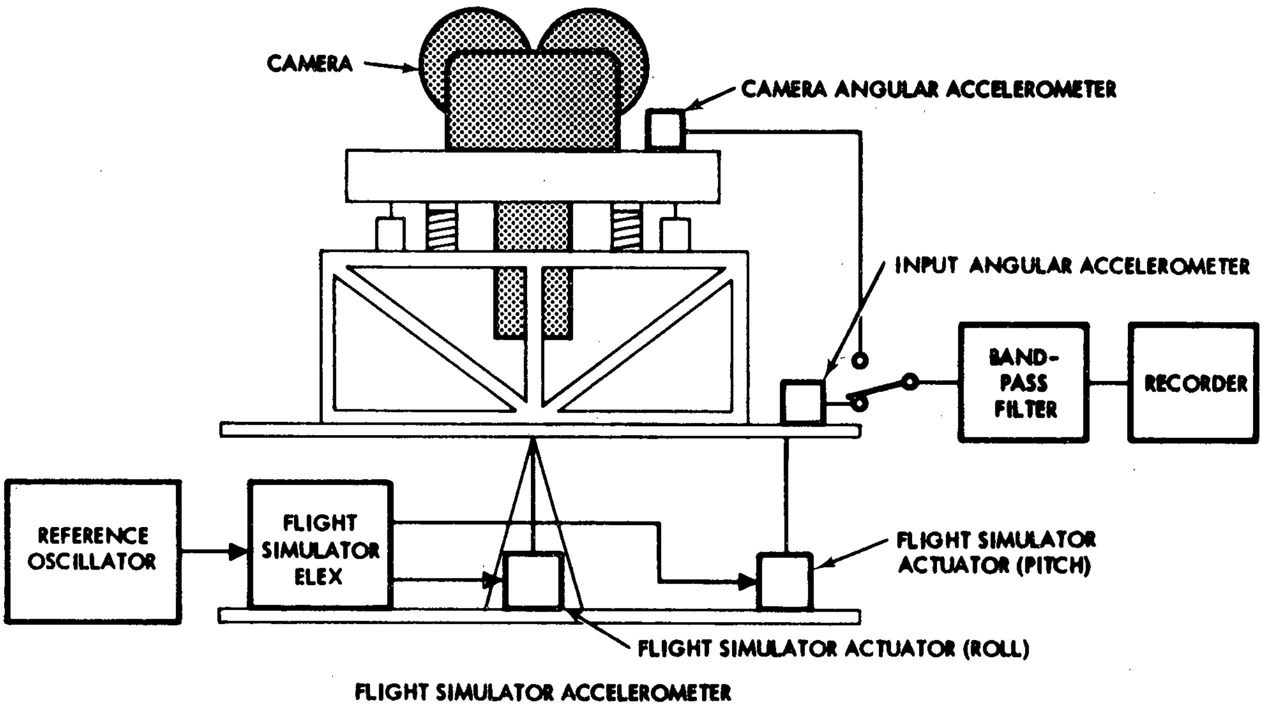


Figure 5-1. Instrumentation Setup for Measuring Transmissibility

Simulator motion is angular about the pitch and roll axes. The axis of rotation is through the main gimbal joints. The mounting stand of the AVI was bolted to the test bed.

To show the comparison between predicted and actual performance, in figure 5-2 several data points for Serial #001 pitch transmissibility are plotted along with the theoretical curves. These data points form a curve that correlates quite well with the predicted curves. Variance is due primarily to measurement error (equipment tolerances) and the fact that actual results tend to describe smooth curves rather than the sharp corners and breaks of asymptotic predictions. Variance was not considered great enough to warrant further analysis.

AVI, serial number 001, pitch and roll curves shown in detail in figures 5-3 and 5-4 reflect this correlation. The slightly erratic shape of the curves above 7 Hz tend to be caused by friction. The peak around 4 Hz is probably due to a coupled mode from translation to rotation. (The flight simulator cannot simulate pure rotation.) The shape of this peak with a dip at slightly higher frequencies is typical of coupled-mode effects.

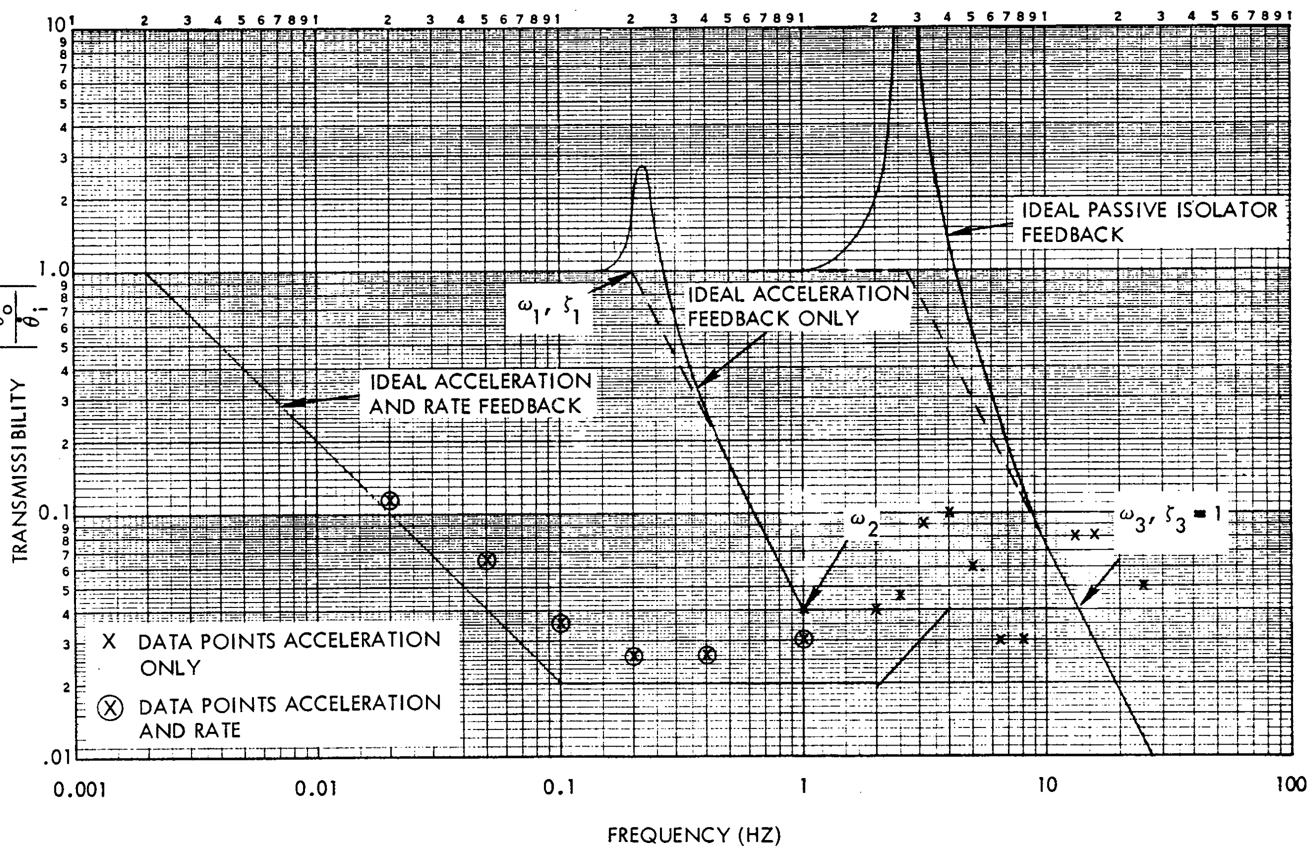


Figure 5-2. Transmissibility

TP6558

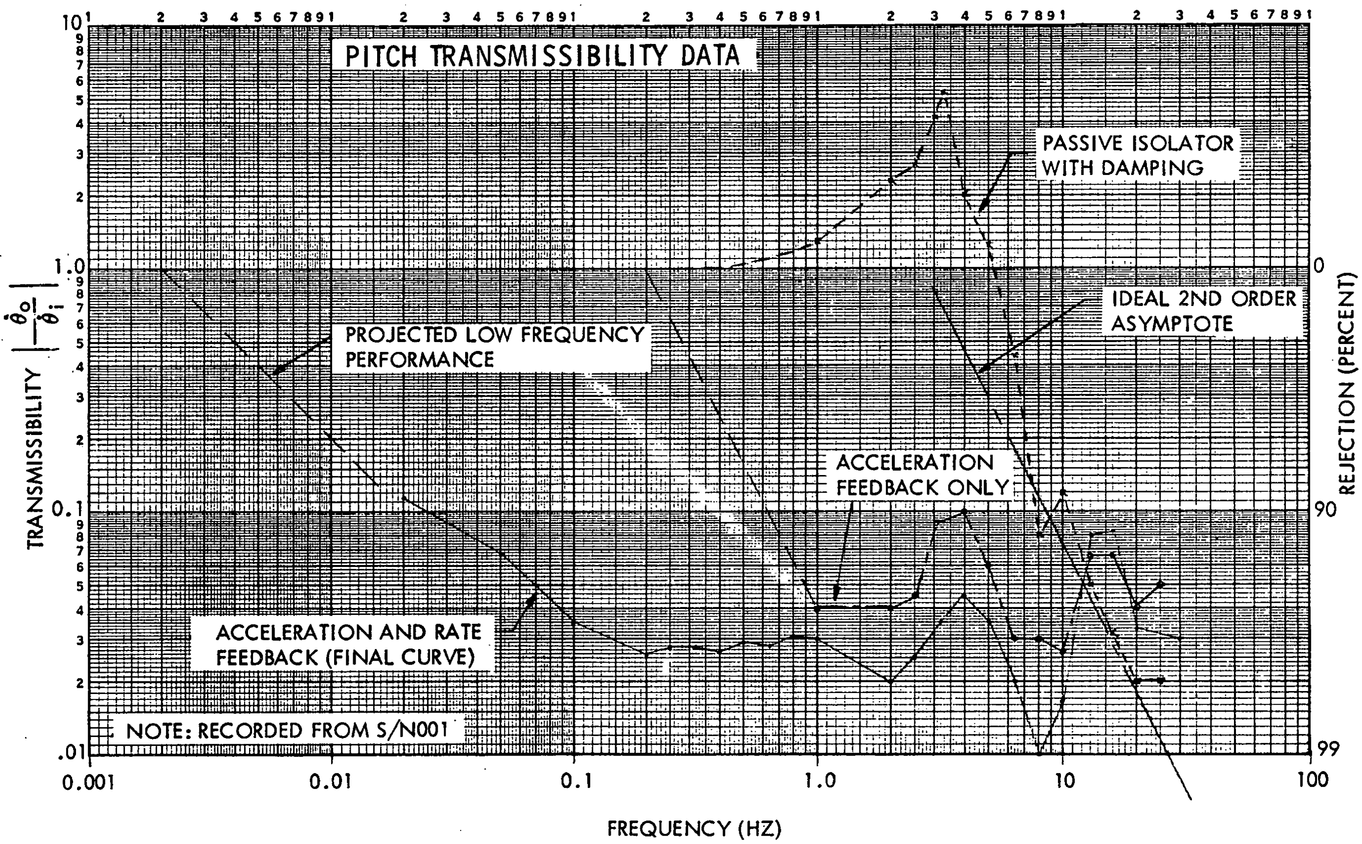


Figure 5-3. Pitch Transmissibility, AVI Serial No. 001

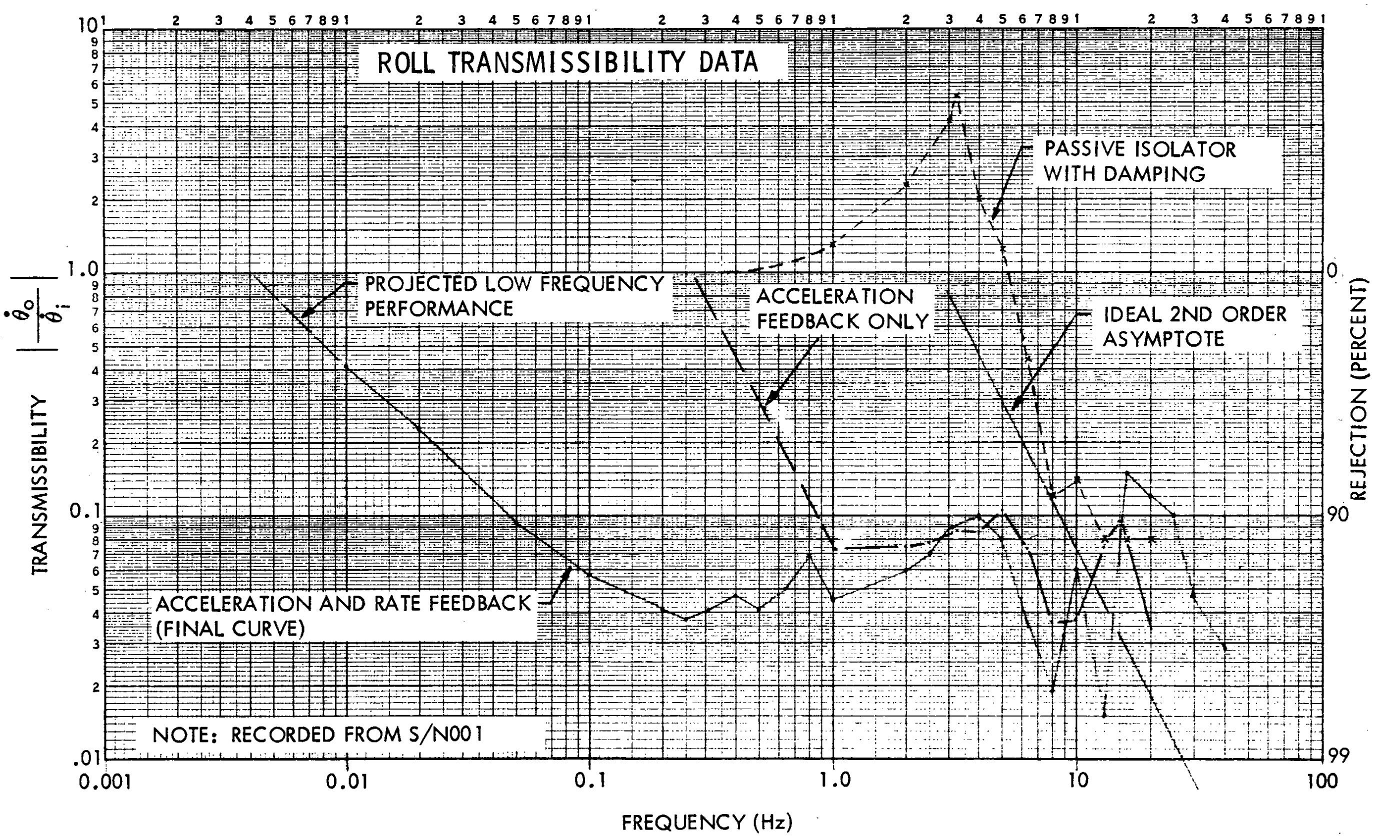


Figure 5-4. Roll Transmissibility, AVI Serial No. 001

TP6558

The transient response of serial no. 001 was observed with several inputs from the simulator. Transient times of 50 to 100 ms are typical for the AVI.

Linearity tests were performed on serial no. 001 by varying the amplitude of a 5-Hz flight simulator input. The transmissibility with a 10 milliradian/sec input (0-peak) was 0.0375. When the input was reduced to 1 milliradian/sec (0-peak), the transmissibility was 0.117. This exceptional rejection at 1 milliradian/sec input means that a residual rate of roughly 0.15 milliradian/sec is feasible.

Testing of serial no. 002 consisted of mechanical design verification, balancing, and servo checkout as described previously. Transmissibility and linearity were measured in both the pitch and roll axes. Figures 5-5 and 5-6 show the results of testing serial number 002. Once again, correlation to the predicted curves is quite good, and also correlation to the curves for serial number 001 is good.

Measurements were also made of the response of the AVI during camera operation. This was done by simultaneously monitoring the shutter command signal and the residual camera acceleration signal. The results showed that the AVI transmissibility was unaffected by camera operation. No degradation in the transmissibility was noted for cg shift due to film transport from supply to takeup spools.

Additional testing was done to determine the effect of camera location variations on the AVI. A person inexperienced with camera installation techniques installed the KS-72 camera using the camera locating fixture and following the camera installation procedure described in the AVI instruction manual. No degradation in AVI performance was measured.

Prior to delivery to WPAFB, AVI serial no. 002 was subjected to explosion and EMI testing to verify aircraft compatibility. The unit successfully passed explosion testing. With the addition of a +28 vdc power line filter, electromagnetic interference was reduced to acceptable limits.

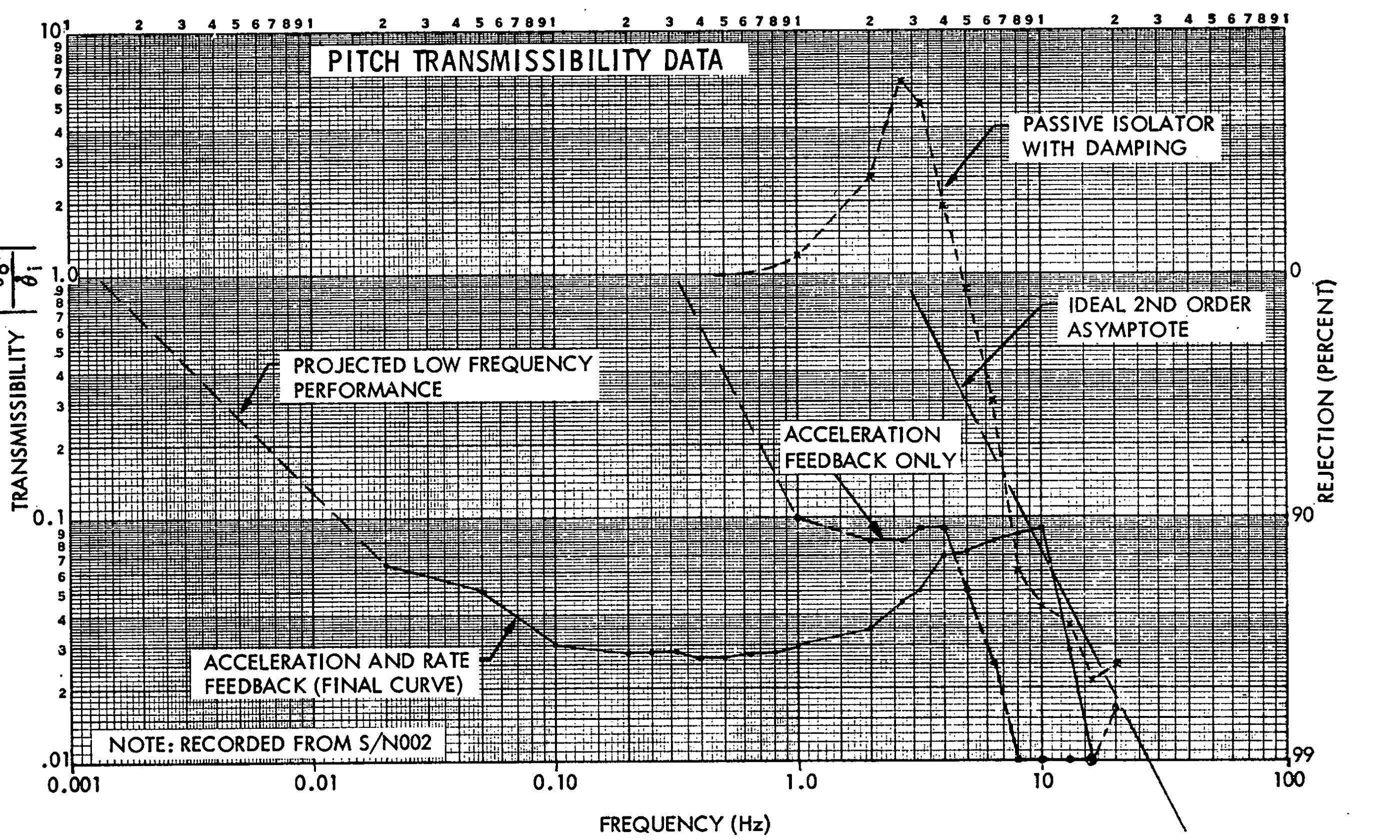


Figure 5-5. Pitch Transmissibility, AVI Serial No. 002

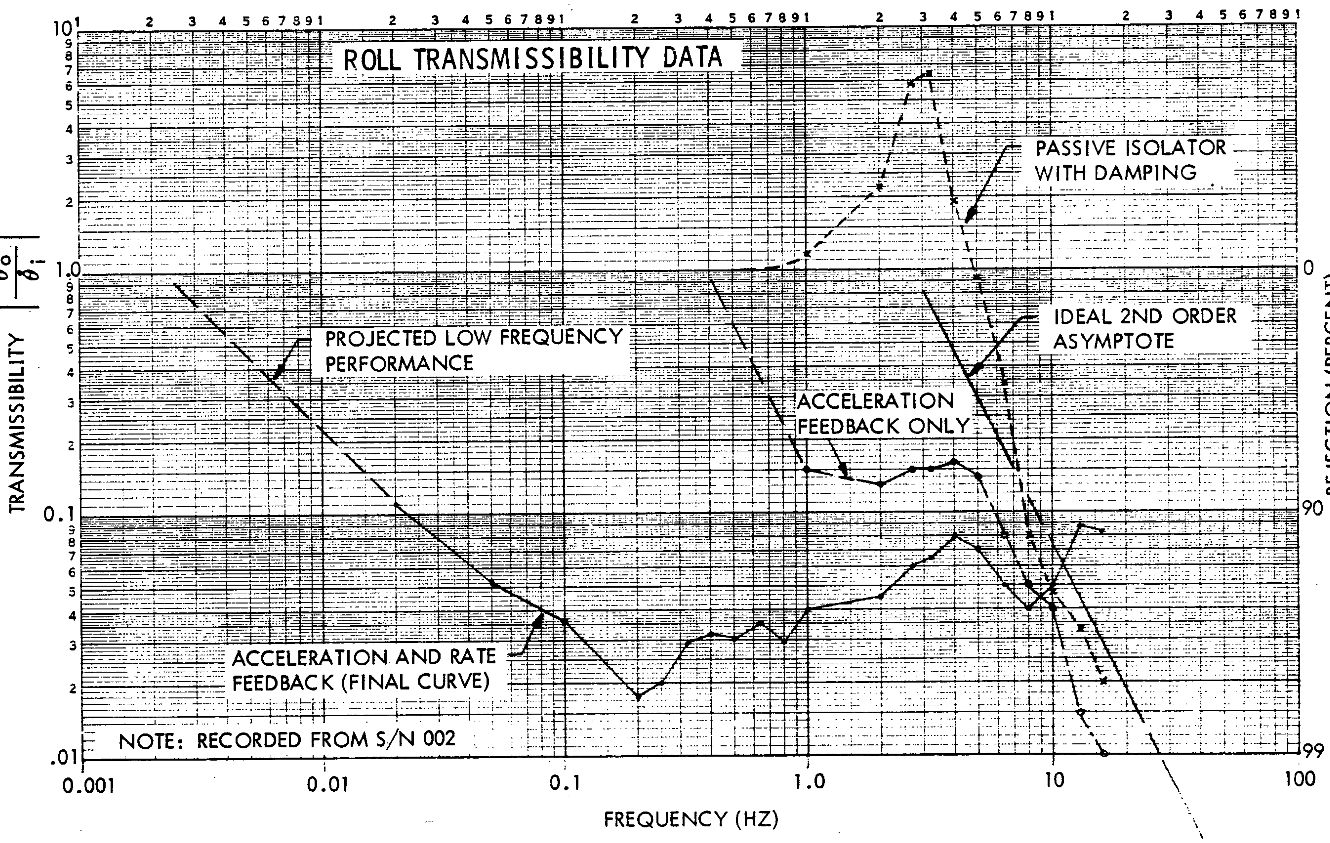


Figure 5-6. Roll Transmissibility, AVI Serial No. 002

hycon

700 ROYAL OAKS DRIVE
MONROVIA, CALIFORNIA